1989

Physiological determinants of rock climbing ability

Wendy Russum
San Jose State University

Order Number 1338719

Physiological determinants of rock climbing ability

Russum, Wendy Patton, M.A.

San Jose State University, 1989

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

Physiological Determinants
of Rock Climbing Ability

A Thesis
Presented To
the Faculty of the Department of
Human Performance
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Arts

By
Wendy Russum
August 1989

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

Craig Cisar

Dr. Craig J. Cisar, Assistant Professor

Carol L. Christensen

Dr. Carol L. Christensen, Assistant Dean

Philip Sierra

Dr. Phillip Sierra, Lecturer

APPROVED FOR THE UNIVERSITY

Serena W. Stanford

ABSTRACT

PHYSIOLOGICAL DETERMINANTS OF ROCK CLIMBING ABILITY

By Wendy Russum

The purpose of this study was to determine the physiological characteristics associated with rock climbing ability and classification in 40 male rock climbers age 20 to 40 yr. Standard labratory procedures were used to measure 14 physiological measurements. Self reported lead capability was used to determine novice, intermediate, and elite groups. Shoulder strength, body weight, and grip strength were identified by stepwise multiple regression as accounting for 45.3% of the variance in climbing ability. Multiple discriminant analysis identified discriminant function 1 (DF1) as representing grip strength/anaerobic characteristics and discriminant function 2 (DF2) as representing physical development characteristics. Discriminant function 1 accounted for 62.5% of the variance, while DF2 accounted for the remaining 37.6% resulting in correct classification of 67.5% of the climbers. In conclusion, development and inclusion of anaerobic characteristics and strength appear to be particularly important to successful rock climbers.

Acknowledgments

I dedicate this project to all of those people who have given me support and encouragement over the last three years. A special thanks to the inspiration for this study Barry E. Bates who told me to "go for it" and help me make that 5.14 pitch. To Carla Phillips and Teresa Hutchinson who were always there for me with both physical and emotional support. To Craig J. Cisar and Carol L. Christensen who supplied me with their expertise and encouragement and to my parents for their support and patience. Finally to Toru who kept me company and was the purrfect lap warmer all those long tedious hours that went into this project. A special thank-you to you all.

Table of Contents

List of Tables

CHAPTER I

Introduction

This chapter is divided into several sections as follows: background for the study, statement of the purpose, research hypotheses, delimitations, limitations, definitions, statistical analysis, and summary.

Background for the Study

Athletes, depending on their specific sport, vary considerably in their physiological attributes (Daniels, 1978). Unlike an athlete's physique many physiological differences are not apparent. It is important to understand characteristics required for success in a particular sport, both to match athletes with a sport and also in training an athlete for their chosen sport (Daniels, 1978). In testing athletes we can define the physiological characteristics necessary for success in their sport. It is important, however, to study each athletic group individually to characterize the physical and physiological attributes required to achieve success in each sport.

In the United States, rock climbing became popular in the early 1950's. At that time, climbing was a social activity, with most climbers belonging to clubs. In the 1960's a few exceptional climbers began to appear. Climbing skills advanced and climbing became a lifestyle for the leading climbers in the country (Loughman, 1981). In the

1970's the world of climbing exploded. There appeared many high school and college climbing courses, climbing magazines and even climbing movies (Loughman, 1981). For the first time, the idea of training became part of the rock climbing scene. Today climbing is a complex and highly sophisticated activity, whose standards have advanced enormously. Climbing competitions are now common in Europe and becoming popular in the United States as well. Climbers are venturing onto even more difficult terrain and the gap between the expert and the beginner has continued to widen (Loughman, 1981). Presently, climbers as a group appear to have been neglected as athletes. There appears to be little or no research done on this group of athletes, so climbers continue to rely on hearsay for training during the off season, and to climb as their mainstay of training.

Physiological overviews have been shown to be good predictors or discriminators in athletes. They have been shown to be useful in predicting performance and/or success in individual athletes (Cisar, Johnson, Fry, Housh & Hughes, 1988; Housh et al., 1984; Pollock, Jackson & Pate, 1980). Profiles have been established for athletes in many sports, but those on well trained upper body athletes are not numerous. Athletes such as kayakers, slalom paddlers, wrestlers, swimmers, volleyball players, and triathletes have been studied (O'Toole, Hiller, Crosby & Douglas, 1987;

Vaccaro, Gray, Clarke & Morris, 1984; Tesch, 1983; Dwyer, 1983; Puhl, Case, Fleck & Van Handel, 1982; Kelly, Gorney & Kalm, 1978; Gale & Flynn, 1974). Studies looking at rock climbers, have been limited to those climbers performing at high altitude and have only looked at the effects of altitude on physical performance. One physiological profile reviewed studied only climbers who had climbed over 8,000 meters. The study's purpose was to see why these climbers were able to function at these altitudes, without supplemental oxygen (Olez et al., 1986). In a study by Baker (1980), only body composition changes were looked at during a climbing expedition at high altitude. However, most rock climbers perform their activities at altitudes below 8,202 feet; at this altitude there is not a significant decline in physical performance, as technique or skill is of primary importance (Astrand & Rodahl, 1986). Since physiological profiling is necessary to determine the physical requirements of a sport, it appears that there is a need for rock climbers to be assessed.

Today, the national parks continue to see an increasing usage of climbing areas. Many of these people are weekend climbers who follow a wide variety of training programs during the week. Athletes such as runners or swimmers have coaches and well-founded training techniques to rely on. Yet, climbers do not appear to have any of this scientific based expertise to utilize. In training any athlete, the training schedule must be geared to an athlete's individual characteristics. Physiological testing would be appropriate for climbers to help establish the characteristics of these athletes and to establish some guidelines for training.

Statement of the Problem

The purpose of this study was to determine the physiological and physical characteristics associated with rock climbing ability.

Approach to the Problem

Forty male rock climbers were studied to assess the following physiological variables: maximum oxygen uptake (VO2 max), ventilatory threshold (VT), anaerobic capacity (AC), anaerobic power (AP), fatigue index (FI), leg strength (LS), arm strength (AS), shoulder strength (SS), body weight (BW), relative fat (RF), lean body weight (LBW), body somatotype (X & Y), and grip strength (GS).

Statement of the Hypotheses

1. There will be no difference in the absolute strength between elite, intermediate, and novice climbers.

2. There will be no difference in grip strength between elite, intermediate, and novice climbers.

3. There will be no difference in body composition and body build between elite, intermediate, and novice climbers.

4. There will be no difference in anaerobic power,

anaerobic capacity, and fatigue index between elite, intermediate, and novice climbers.

5. There will be no difference in maximal oxygen uptake and ventilatory threshold between elite, intermediate, and novice climbers.

Delimitations

This study was delimited to 40 healthy male volunteers, between the ages of 20 to 40 years. All subjects were climbers who could complete climbs at the 5.0 level or above, but were not class 6 climbers.

Limitations

The factors in this study which were not controlled included: motivation level of each subject, present training level, genetic make-up of the subjects, nutritional status, and pretesting activity. The study was also limited by the accuracy of each individual's self rating of their climbing ability and reported physical activity history.

Definition of Terms

Aerobic Endurance (AE). The ability to continue physical activities that rely on oxygen for energy production (Lamb, 1984).

Anaerobic Capacity (AC). Anaerobic capacity reflects the glycolytic (lactic) component and the alactic component of energy release (Tharp, Newhouse, Uffelman, Thorland & Johnson, 1985). It represents the total work/time (kgm/30-

sec) and is calculated by the following formula: (0.06 kg leg resistance X kg of body weight X 6 X the highest number of revolutions of the flywheel in a 30-sec period) + (0.05 kg arm resistance X kg body weight X 6 X the highest number of revolutions of the flywheel in a 30-sec period) (Bar-Or, 1978; Tharp et al., 1985).

Anaerobic Power (AP). Anaerobic power reflects the alactic phosphogen component of anaerobic energy release (Tharp et al., 1985). It represents the highest work performed during a 5-second (kgm/5-sec) period and is calculated from the formula: (0.06 kg leg resistance X kg body weight X 6 X the highest number of revolutions of the flywheel in a 5-sec period) + (0.05 kg arm resistance X kg body weight X 6 X the highest number of revolutions of the flywheel in a 5-sec period) (Bar-Or, 1978; Tharp et al., 1985).

Body Density (Db). Body density is the body weight per unit of body size (kg/l) and is calculated with the following formula: body density = body weight / body volume (Fox & Mathews, 1981).

Body Somatotype (X & Y). Body somatotype is defined by coordinates X and Y. It is composed of a coordinate grid superimposed over a somatochart. Individual coordinate points can be plotted on the chart using the following formulas: X = ectomorphy - endomorphy, and Y = (2 * mesomorphy) - (endomorphy + ectomorphy). Variable X is a descriptive measure of linearity - fatness and variable Y is a descriptive measure of muscularity (Ross & Wilson, 1973).

Body Volume (BV). Body volume is the size of the body expressed in liters and is calculated by the formula: body volume = [(body weight - true underwater weight)/ water density] - residual volume (Fox & Mathews, 1981).

Body Weight (BW). Body weight is the total weight of all body tissues expressed in kilograms (kg).

Fat Weight (FW). Fat weight reflects the kg of body weight consisting of adipose tissue, which does not include essential fat (Brozek, Grande, Anderson & Keys, 1963). It is calculated with the following formula: fat weight = body weight X relative fat.

Fatigue Index (FI). Fatigue index reflects the oxidative capacity of the muscles. A higher FI indicates a greater proportion of fast-twitch fibers and a lower proportion of slow-twitch fibers in the muscles (Inbar et al., 1979). It is calculated as the highest 5-sec power for legs minus the lowest 5-sec power for legs, divided by the highest 5-sec power for legs X 100 plus highest 5-sec power for arms minus the lowest 5-sec power for arms, divided by the highest 5-sec power for arms X 100 (Bar-Or, 1983).

Lean Body Weight (LBW). Lean body weight is the kg of body weight that is composed of lean tissues plus essential fat (Brozek et al., 1963). The formula is: lean body weight = body weight - fat weight.

Leg Strength, Arm Strength, and Shoulder Strength (LS, AS, and SS). Leg, arm, and shoulder strength are the absolute peak torque values expressed in ft/lbs for the dominant leg and arm, in extension movements at 180 degrees/sec. (*Isokinetic - Joint Testing & Exercise: A handbook for Cybex II+ and U.B.X.T.*, 1983).

Maximal Oxygen Uptake (VO2 max). Is the greatest volume of oxygen used by the cells of the body per unit of time (l/min). In this study VO2 max was defined as: (1) a heart rate within 10 beats per minute (bpm) of age predicted maximum, (2) respiratory quotient (RQ) of 1.0 or greater, and/or (3) oxygen uptake plateaus or begins to decrease with increasing work loads (Fox & Mathews, 1981).

Relative Fat (RF). Relative fat is the portion of the body weight composed of adipose tissue and is calculated from this formula: RF = [(4.57/Db) - 4.142] X 100 (Brozek et al., 1963).

Residual Lung Volume (RV). Residual lung volume is the volume of air left in the lungs upon maximal exhalation. This volume must be taken into account when measuring body composition by hydrostatic weighing (Lamb, 1984).

Ventilatory Threshold (VT). Ventilatory threshold is the onset of metabolic acidosis (anaerobic metabolism) and is identified as the oxygen uptake value (l/min) at the point of (1) a nonlinear increase in ventilation (VE), (2) a nonlinear increase in carbon dioxide production (VCO2), (3) an increase in end-tidal oxygen (FEO2) without a corresponding decrease in end-tidal carbon dioxide (FECO2), and (4) an increase in RQ (VCO2/VO2) with increasing workloads of an incremental test (Wasserman, Whipp, Koyal & Beaver, 1973).

Climbing Definitions

Classes. Sierra Club rating of technical difficulties of a climb (Loughman, 1981).

Class 3. Climbing: a rope should be available for inexperienced climbers (Loughman, 1981).

Class 4. Exposed climbing: a rope and belay are advisable (Loughman, 1981).

Class 5. Difficult free climbing: protection anchors for leaders are advised (Loughman, 1981).

Class 6. Aided Climbing: the rope and anchors are used for assistance in moving upward (Loughman, 1981).

Decimal System. A way of rating technical difficulty of routes/climbs. A decimal point and a number ranging from 0 - 13 (0 being the least difficult) are appended to a class 5 climb (i.e., 5.8 or 5.11). Each numeral covers a wide range of difficulty, now commonly differentiated by the letters a, b, c, and d (i.e., 5.11d or 5.8a) (Loughman, 1981).

Elite Climber. A climber who can consistently lead a 5.11 climb/route or better.

Intermediate Climber. A climber who can consistently lead a 5.9 - 5.10d climb/route.

Novice Climber. A climber who can complete at least a 5.0 free climb to a 5.8d level climb/route.

Statistical Analysis

Descriptive statistics (*M*, *SD*, and range) was used to describe the physiological characteristics of the elite, intermediate, and novice climbers. Group differences between the elite, intermediate, and novice climbers were assessed using a one-way analysis of variance and a Tukey post-hoc test for each physiological variable.

Full-model and stepwise multiple regression were used to examine the relationship of the physiological variables to the climber rating for all groups of subjects. Multiple discriminant analysis was used to determine which variables discriminated between the climbing ability of the elite, intermediate, and novice climbers.

In addition Pearson product-moment correlations were used to examine the intercorrelations between the selected physiological variables and climber rating. The computer program SPSSx (*SPSSx User's Guide*, 1983) was used for statistical analysis of data. The alpha level for statistical significance was $p \leq .05$.

CHAPTER II

Review of Literature

Introduction

Some physiological attributes have long been associated with success in specific sports. Astrand and Rodahl (1987) list energy output, neuromuscular function, and physiological factors as the major influences in physical performance. Some attributes which have been found to respond to training are strength, neuromuscular coordination, mechanical efficiency, maximal oxygen uptake, cardiac output, ventilation, blood lactate levels, anaerobic capacity, recovery rate, and heat dissipation (Astrand & Rodahl, 1987). In order to determine which physiological factors might be important to test in rock climbers, a search of literature was done. Studies conducted with well trained upper body athletes, were reviewed to see which physiological attributes were measured and how they were measured.

Physiological Profile

Studies that have looked at rock climbing have focused on the effect of altitude and hypoxia on performance. Oelz et al. (1986) studied the functional characteristics of six world class high altitude mountaineers. Some of the parameters measured were static and dynamic lung volumes, echocardiographic measures, muscle fiber type, and capillary cross-sectional area. Subjects' average age was 40.7 yr, while average height (hgt) and BW were 176.0 ± 4.4 cm and 71.2 ± 7.7 kg, respectively. Lung volumes and echocardiographic measures were found to be within normal limits, when compared to sedentary controls. Muscle fiber distribution was 70% type I, 22% type IIa, and 7% type IIb fibers. The number of capillaries per unit of cross-sectional area was significantly greater than controls. Total mitochondrial volume was not significantly different from controls, but the subsarcolemmal component was equal to that of a long distance runner's. Average VO2 max was 60 ± 6 ml/kg/min, while the average maximal anaerobic power was 28 ± 2.8 w/kg (vertical jump force). All subjects were characterized by resting hyperventilation both in normoxia and in moderate hypoxia. The authors concluded that elite high altitude climbers do not have physiological adaptation to high altitude that can justify their unique performance (Oelz et al., 1986).

Baker (1980) looked only at body composition changes during a four week alpine climbing expedition. Baker found a three percent reduction in body fat after the four week program. There was also a reduction in the ratio of absolute body fat to lean mass.

In reviewing the literature that has been published, there appears to be no physiological profiles assessing the physical characteristics of rock climbers. Nor has there been an assessment made on physiological characteristics and their relationship to climbing performance.

In looking at elite flat-water kayakers, Tesch (1983) concluded that kayakers needed not only high aerobic power, but also high anaerobic energy yield and great upper body strength. Tesch (1983) used three types of exercise to measure maximal oxygen uptake: treadmill running (TM), arm cranking, and outdoor paddling. The VO2 max on the TM averaged 5.36 $\pm$ 0.25 l/min, while values for arm cranking and paddling were 4.30 $\pm$ 0.3 l/min and 4.6 $\pm$ 0.2 l/min, respectively. It appears from this study that aerobic power, anaerobic yield, and muscular strength are indicators of success in kayakers (Tesch, 1983).

Vaccaro et al. (1984) reviewed body composition, somatotype, VO2 max, and heart rate, in world class white water slalom paddlers. The mean descriptive information was age = 20.1 yr, hgt = 180.34 cm, BW = 76.3 kg, RF = 10.4%, and LBW = 68.3 kg. The paddlers' body type by somatotyping was found to be predominantly mesomorphic. Aerobic capacity was tested both on the TM and arm cranking resulting in VO2 max values of 60.1 $\pm$ 13.6 ml/kg/min for TM and 54.0 $\pm$ 6.9 ml/kg/min for arm cranking. The paddlers were able to reach 86% of their TM VO2 max when arm cranking alone was measured. It appears that top paddlers are better adapted to arm work than the average athlete (Vaccaro et al., 1984).

Puhl et al. (1982) tested physiological and physical characteristics of elite male volleyball players. The tests used were VO2 max determined from a maximal TM test, vertical jump for anaerobic power, body composition from hydrostatic weighing, and peak isokinetic strength as measured on a Cybex II dynamometer. Descriptive characteristics of the subjects were age = 26.1 $\pm$ 3.5 yr, hgt = 192.7 $\pm$ 3.9 cm, BW = 85.5 $\pm$ 4.5 kg, LBW = 76.5 $\pm$ 8.5 kg, RF = 12.0 $\pm$ 2.5%. Subjects were found to have an aerobic capacity of 4.80 l/min (56.1 $\pm$ 2.2 ml/kg/min), while vertical jump was 67.0 $\pm$ 11.0 cm. Values obtained from strength testing were arm strength of 18.5 ft/lbs at 180 degrees/sec, leg strength of 65 ft/lbs at 180 degrees/sec, and shoulder strength of 50 ft/lbs at 180 degrees/sec.

Two recent physiological profiles were done on triathletes (O'Toole et al., 1987; Kohrt, Morgan, Bates & Skinner, 1987). Triathletes may be unique as athletes as they are endurance athletes who are well trained in both upper and lower body. O'Toole et al. (1987) developed their profile using anthropometric measurements and oxygen uptake during maximal exercise by TM, cycle ergometer (CE), and arm cranking. Eight male Ironman competitors were tested. The results of the competitors' VO2 max tests were 5.10 $\pm$ 0.85 l/min on TM, 4.97 $\pm$ 0.91 l/min on CE, and 3.65 $\pm$ 0.74 l/min on arm cranking. Descriptive statistics of the triathletes studied were compared to those of other elite athletes (swimmers, cyclist, and runners) in Table 1. When comparing the VO2 max obtained, the male triathletes were most comparable to swimmers. As the mean maximal oxygen uptakes values were 78.8 ml/kg/min on the TM for runners, 74.4 ml/kg/min on the CE for cyclists, 68.6 ml/kg/min on the TM for swimmers, 72 ml/kg/min on the TM for elite triathletes.

Kohrt et al. (1987) looked at the responses of triathletes to maximal swimming, cycling, and running. Thirteen triathletes (M age = 29.5 yr) with an average of two years triathlon experience were tested. Maximal oxygen uptake were measured on a TM, CE, and with tethered swimming (TS). The average VO2 max for each test were 60.5 ml/kg/min for TM, 57.9 ml/kg/min for CE, and 52.5 ml/kg/min for TS.

One body somatotyping study was found on male gymnasts where forty-seven gymnasts participating in the 1986 A.A.U. senior national championship were studied (Carter, Sleet & Martin, 1971). The gymnasts were classified into (1) highly-successful finalists qualifying in the top 6 places in events (n=11) and (2) less-successful, gymnasts who did not qualifying (n=36). The purpose of the study was to differentiate by size and somatotype highly-successful and less-successful gymnasts and secondly to compare the highly-successful gymnasts to four diverse groups of outstanding gymnasts from previous studies. The analysis was based on

Table 1

Summary of Data Comparison of Elite Triathletes to Other Elite Athletes (O'Toole et al. 1987)

Athletes	Age (yrs)	Height (cm)	Weight (kg)	Body fat (%)
Triathletes	30.5 $\pm$ 8.8	178.8 $\pm$ 6.6	74.7 $\pm$ 10.0	9.9 $\pm$ 3.5
	20-50	169-191	68-94	4.9-15.2
Swimmers	19-20	179-184	73-78.4	9-12
Cyclist	>18	180.3	67.3-74	8.8
Runners	26.8	176-179	63-66	1.4-8.0

Note. Triathletes are reported in mean $\pm$ *SD* and range, while single sport athletes are reported by only range.

measures of hgt, BW, hgt-wgt ratio (HWR), endomorphy, mesomorphy, and ectomorphy (Heath-Carter index). The findings indicated that the highly-successful gymnasts were more mesomorphic than the less-successful athletes (Carter et al., 1971). The mean values of the less-successful athletes were age = 23.3 yr, hgt = 169.2 cm, BW = 64.7 kg, HWR = 12.75, and 2.1-5.9-2.2 somatotype. The highly-successful gymnasts' mean values were age = 22.3 yr, hgt = 165.1 cm, BW = 61.9 kg, HWR = 12.66, and 1.9-6.4-2.0 somatotype. It was also found that outstanding gymnasts from diverse groups were equally mesomorphic, but differed significantly in hgt, BW, HWR, endomorphy, and ectomorphy. The difference between these groups and the highly-successful athletes of this study, may be due to the date of the previous studies (time), training, type of gymnastics, or ethnic factors (Carter et al., 1971).

No recent profiling studies were found that included grip strength as a measurement. However, Mathiowetz et al. (1985) studied adults in the Milwaukee region to establish clinical norms for grip strength. The Jamar dynamometer was used to test 310 men for hand strength evaluation using standardized positioning and instructions. The highest grip strength scores occurred in the 25 to 39 age groups. Means $\pm$ SD values by age group were: 20-24 yr = 54.9 $\pm$ 9.3 kg, 25-29 yr = 54.7 $\pm$ 10.4 kg, 30-34 yr = 55.3 $\pm$ 10.2 kg, 35-39 yr =

54.3 ± 10.9, and 40-44 yr = 53.0 ± 9.4. Mathiowetz et al. (1985) found a relatively small difference between right hand grip and left hand grip scores.

One group of athletes who might be most comparable in physiological parameters to rock climbers, may be wrestlers. Some of the characteristics which are important for success in wrestling may be similar to what is hypothesized to be important for climbers. For example, low percentage body fat and a high strength to weight ratio. The following articles on wrestlers were reviewed.

Kelly, Gorney, and Kalm (1978) looked at the effects of a college wrestling season on 19 university wrestlers (*M* ± *SD* age = 20.3 ± 1.3 yr). The authors measured hgt, BW, body diameters, body composition, and muscular strength and endurance (Cybex II dynamometer). All measurements were taken pre, peak, and post season, however few significant changes were noted during the course of the season. Table 2 summarizes the results of this study.

Gale and Flynn (1974) described anthropometric and physiological characteristics of successful, high ability wrestlers, who competed in the U.S. Olympic trails. Results are given in Table 3. There were no differences in the means of the aerobic capacities of those who made the U.S. Olympic team and those who did not. These VO2 max values were much lower than values previously reported on endurance athletes.

Table 2

Results of a College Wrestling Season on Physiological Variables of 19 University Wrestlers (Kelly et al., 1978)

Variables	Preseason	Peak season	Postseason
Weight (lbs)	159.0± 21.7	156.7± 23.0	158.9± 21.1
Height (cm)	174.5± 7.4		
Lean body/ weight (lbs)	141.8± 18.0	143.1± 20.0	142.2± 19.9
Body fat (%)	10.8± 1.7	8.4± 1.8	10.5± 2.1
Maximal oxygen uptake/ (ml/kg/min)	58.6± 6.4	61.0± 5.8	57.2± 7.2
Leg strength/ (ft/lbs)	83.3± 13.7	87.6± 22.6	*117.3± 8.9
Shoulder strength/ (ft/lbs)	80.3± 24.0	82.9± 26.9	*108.8± 22.0

Note. Values are mean ± *SD*.

* Post significantly greater than pre and peak.

Table 3

<u>Physical and Physiological Characteristics of High Ability Wrestlers in U.S. Olympic Trail (Gale & Flynn, 1974)</u>

Group	*n*	Age (yr)	Hgt (cm)	Wgt (kg)	FFB (kg)	VO2max (ml/kg/min)	VO2max (l/min)
Olympic/ team	9						
M		27.0	176.0	75.7	68.2	54.3	4.1
SD		±4	±14	±18.7	±16.3	±6.5	
Non/ Successful	8						
M		23.0	174.0	71.0	63.5	54.8	3.9
SD		±4	±12	±16.6	±13.8	±4.1	

<u>Note</u>. Anthropometric and physiological values are reported as mean ± <u>SD</u>.

The mean estimated RF for those wrestlers trying to lose or maintain weight was 9.8%.

Cisar et al. (1987) studied the ability of preseason body composition, body build, and strength to predict wrestling success in an upcoming competitive wrestling season. Fifty-five male high school (M ± SD age = 16.2 ± 1.0 yr) wrestlers were assessed for body composition (hydrostatic weighing), anthropometric measurements for body build characteristic, and isokinetic (Cybex II) measures of muscular strength. Wrestling success was evaluated by the wrestling won-loss record: 14 were determined highly skilled, 13 average, and 28 were determined as novice wrestlers. Results showed mean scores of hgt = 170.25 cm, BW = 62.2 kg, RF = 10.7 %, FW = 6.76 kg, and LBW = 55.5 kg. Results of the leg and arm isokinetic strength testing at 180 degrees/sec were arm extension strength = 23.3 ± 6.14 ft/lbs, arm flexion strength = 24.0 ± 7.46 ft/lbs, leg extension strength = 72.67 ± 16.9 ft/lbs, and leg flexion strength = 47.4 ± 13.2 ft/lbs. Results of anthropometric measurements of all the subjects resulted in an endomorphic rating of 2.77 ± 0.93, mesomorphic rating of 4.49 ± 0.88, and an ectomorphic rating of 3.15 ± 0.95. Body somatotyping for the highly skilled resulted in mean ratings of X equals -0.33 ± 0.81 and a Y equals 3.93 ± 0.60. Multiple discriminant analysis was used to examine the preseason variables to predict success during the wrestling season. The multiple discriminant analysis indicated two functions. Discriminant function 1 (DF1) consisted of forearm extension/BW-300 degrees/sec, leg flexion/BW-180 degrees/sec, forearm extension/BW-30 degrees/sec, forearm flexion/BW-300 degrees /sec, forearm extension/BW-180 degrees/sec, leg flexion/BW-300 degrees/sec, forearm flexion/BW-30 degrees/sec, leg extension/BW-180 degrees/sec, leg extension/BW-300 degrees /sec, leg extension/BW-180 degrees/sec, and factor Y). Discriminant function 2 (DF2) consisted of X, forearm flexion/BW-180 degrees/sec, LBW, RF, wgt/hgt, leg flexion/BW-30 degrees/sec, and body breath dimensions. Each function accounted for 50% of the variation between groups. Discriminant function 1 included variables that were related to strength relative to weight. Discriminant function 2 was comprised of body composition and body build variables. Results of this study indicated that highly skilled wrestlers tended to have lower relative fat, body breath dimensions, and linearity -fatness scores, while having greater muscloskeletal size, muscularity, and greater relative strength to body weight than did the average or novice wrestlers. Sixty-four percent of the highly skilled wrestlers and 75% of the novice wrestlers were correctly classified by the DF1 and DF2 variables. However only 8% of the average wrestlers were correctly classified. Cisar et al. (1987) suggested that the variables measured were only sensitive in predicting success for the novice and highly skilled wrestlers, but not for those of average ability.

Measures of Aerobic Capacity

In reviewing profiles of various athletes, a number of different measures of aerobic capacity have been used. It appears that usually arm cranking and cycle ergometer elicits lower maximal uptakes than does tread mill running. However, well trained upper body (WTUB) athletes appear to reach higher percentages of their VO2 max than other athletes when using upper body alone (Vaccaro, et al., 1984). The following articles were reviewed to determine the validity of using various measures of VO2 max on WTUB athletes, especially in regards to combined arm and leg (A&L) work.

Gleser, Horstmand, and Mello (1984) used ten healthy males to determine whether combined A&L work resulted in a VO2 max greater than that obtained with leg work alone. Their results indicated that VO2 max is 10% higher with the combined A&L work than with legs alone. The mean VO2 max for legs only was 3.09 l/min, where as A&L combined equaled 3.39 l/min. Maximum heart rate did not differ between the two types of work. The authors concluded that the additional muscle mass used during the A&L ergometry allowed the athletes to attain a higher VO2 max.

Reybrouck, Hugenhauser, and Faulker (1975) used only three subjects but each performed a total of 11 maximal tests during the course of the study. The authors' purpose was to look at the effect of arms, legs, and combined A&L ergometry on oxygen uptake, cardiac output, ventilation, and VT. The results showed that the VO2 max in arm ergometry averaged 68% of the VO2 max measured in leg ergometry, but only 60% of the max obtained with the combined A&L work. The two subjects with VO2 max of less than 45 ml/kg/min had a mean VO2 max on A&L ergometry 19% higher than the one obtained using legs only. However, the subject with a VO2 max of 64 ml/kg/min showed no change between work tasks. The authors suggested that the differences seen in this study were due to differences in cardiac output, skeletal blood flow, and the degree to which a subject is conditioned for leg work.

Bergh, Kanstrup, and Ekblom (1979) determined VO2 max on ten men (*M* VO2 max = 60.7 ml/kg/min) using various combinations of arm and leg work during uphill running, cycle ergometry, arm cranking, and A&L cranking. Subjects performed the A&L ergometry with arm intensities at 10%, 20%, 30%, and 40% of the total intensity. Mean VO2 max values were 4.44 l/min for running, 4.12 l/min for bicycling, 3.01 l/min arm cranking, and 4.32, 4.34, 4.27, and 4.01 l/min for combined A&L work at 10%, 20%, 30%, 40% arm work to total intensity. It was concluded that VO2 during maximal exercise is dependent on the muscle mass involved and that A&L work is influenced by the ratio of arm work to total rate of work. Optimum work load for arms, during A&L ergometry, was found to be at 20% of total work intensity. This however is influenced by a subject's fitness for arm work as well as for bicycling (Bergh et al., 1976).

Seals and Mullin (1982) used WTUB athletes to look at VO2 max in a variety of exercise: arm cranking, CE, TM, and a combined A&L task. The purpose of the study was to ascertain if differences existed in VO2 max obtained in the above mentioned modes of exercise between groups of non-WTUB subjects and WTUB athletes. The mean results for all groups are reported in Table 4. The VO2 max values for A&L ergometry were 115%-113% higher than those obtained by CE. The VO2 max for TM and A&L tests were not significantly different for crew, gymnasts, or swimmers. However, wrestlers and non-WTUB subjects did have A&L values that were significantly lower than their TM values. Results indicate that WTUB athletes attained higher VO2 max values in arm cranking. Well trained upper body athletes were able to obtain 80-90% of their CE VO2 max in the arm cranking test, as compared to non-WTUB subjects who obtained only 60-70%. It was concluded that WTUB athletes attain higher VO2 max than non-WTUB individuals when the exercise involves the upper body.

Table 4

Comparison of Well Trained Upper Body Athletes Maximal Testing on Various Protocols (Seals & Mullin 1982)

Subjects	*n*	Body Weight (kg)	Work	VO2 max (l/min)
Crew	12	83.8	TM	4.86
			A&L	5.06
Gymnast	11	67.8	TM	3.95
			A&L	3.88
Swimmers	11	79.0	TM	4.67
			A&L	4.89
Wrestlers	10	76.8	TM	4.69
			A&L	4.32
Untrained	12	68.7	TM	3.81
			A&L	3.62

Note. The values reported are the mean values for the group.

Summary

Some of the physiological and physical measures that studies reviewed were body composition, anthropometric measurements, VO2 max, dynamic strength, and muscular endurance. These profiles have used various tests to measure these physical and physiological characteristics. The tests and procedures that were most frequently used were: (1) body composition, as measured by hydrostatic weighing with a residual lung volume measurement, (2) muscular strength for arm and leg extension and flexion using a Cybex II isokinetic dynamometer, (3) grip strength determined by an adjustable dynamometer, (4) anaerobic power as measured by vertical jump force, and (5) aerobic capacity as measured by a graded stress test. It appears that WTUB athletes do obtain higher VO2 max values in tests which involve upper body as well as lower body work. This suggests that in WTUB athletes an arm-leg task should be used to measure VO2 max.

Literature indicates that profiling can be useful in identifying important characteristics in elite athletes. A profile may be able to identify variables that separate elite from average athletes. Since there is support for profile studies, it seems justified that a profile study on rock climbers should be undertaken to establish their physiological characteristics.

CHAPTER III

Methods

Introduction

This chapter provides information on the subjects, the measurements and methods used, the experimental design, and the statistical analysis.

Subjects

The subjects were males between the ages of 20 to 40 years. Subjects were divided into three groups by self rating of climbing ability (Appendix B). Elite rock climbers were classified as those climbers who stated that they lead climbs of 5.11 - 5.13 plus. Intermediate climbers were climbers who stated that they lead 5.9 - 5.10d climbs. Novice climbers were climbers who stated that they climbed 5.0 - 5.8d climbs. There were a total of 14 thesis variables measured so that a minimum of 40 subjects were needed for the statistical analysis (Jackson, 1984). The groups consisted of 8 elite climbers, 20 intermediate climbers, and 12 novice climbers. Subjects were recruited randomly so that the first 41 applicants were taken, which resulted in the uneven grouping of subjects. All subjects completed and/or signed a health/medical history questionnaire, a climbing and activity history form (Appendix B), and a consent form (Appendix A, approved by the Institutional Review Board of S.J.S.U.).

The stated climbing history and self-rating were used in placement of individuals into groups.

Instrumentation

Testing proceeded in the following order for all subjects tested.

1. Strength measurements
   - static grip strength
   - leg extension at 180 degrees/sec
   - forearm extension at 180 degrees/sec
   - shoulder extension at 180 degrees/sec
2. Anthropometric measurements
   - X and Y components
   - skinfolds
3. Anaerobic power, capacity, and fatigue index
   - combined arm and leg ergometry
4. Body composition
   - body weight
   - lean body weight
   - relative fat
5. Maximal oxygen uptake and ventilatory threshold
   - combined arm and leg ergometry

Each subject took between 2.5 to 3 hours to complete all the testing, so that a maximum of three subjects were scheduled per test session.

Strength Measures

Leg Strength

Leg strength was measured on a Cybex II+ isokinetic dynamometer. Subjects were seated on the Cybex bench with the thigh, hip, and chest stabilized by velcro straps. The dynamometer's axis of rotation was adjusted so it aligned with the subject's anatomical axis of rotation at the knee joint. Then the distal end of the lever arm was strapped to the subject's leg just proximal to the malleoli of the ankle (Isolated - Joint Testing & Exercise: A handbook for using the Cybex II+ and the U.B.X.T., 1983).

Leg strength was determined from the subject's dominant leg (as determined by subject's stated kicking preference) extension through a 90 degree range of motion that ended at full extension at the knee. Three submaximal trails preceded the actual testing, in order to warm-up the subject's leg. The subject executed three maximal extensions at 180 degrees /sec. The highest peak torque was measured and used (Clarkson et al., 1982; Gilliam et al., 1979; Housh et al., 1984; Haymes & Dickinson, 1980).

Arm Strength

Arm strength was measured on the Cybex II+ isokinetic dynamometer using the U.B.X.T. attachments. Subjects were placed in a reclining position on the U.B.X.T. bench, with their upper body stabilized by a velcro strap. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the elbow joint. The "effective input arm" was determined by measuring from the lateral epicondyle to the thumb webspace on the subjects arm. The length of the testing accessory was then adjusted accordingly (Isolated - Joint Testing & Exercise : A handbook for using the Cybex II+ and the U.B.X.T., 1983).

Arm strength was determined from the subject's dominant arm (determined by throwing preference) extension through a 90 degree range of motion. Three submaximal trails preceded the test as a warm-up. The subject then executed three maximal extensions at 180 degrees/sec. The highest peak torque value was measured and used (Clarkson et al., 1982; Gilliam et al., 1979; Housh et al., 1984; Haymes & Dickinson, 1980).

Shoulder Strength

Shoulder strength was measured on the Cybex II+ isokinetic dynamometer using the U.B.X.T. attachments. The subject was placed in a reclining position on the U.B.X.T. bench, with the upper body stabilized by a velcro strap. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the shoulder joint. The "effective input arm" length was determined by bringing the subject's arm to full extension above the shoulder, and then measuring from the glenohumeral joint to the thumb webspace of the subject's arm. The length of the testing accessory was then adjusted accordingly (Isolated - Joint Testing & Exercise: A handbook for using the Cybex II+ and the U.B.X.T., 1983).

Shoulder strength was determined from the subject's dominant shoulder (determined by throwing preference) extension through a 180 degree range of motion. Three submaximal trails preceded the test for warm-up purposes. The subject was reminded to keep the arm fully extended during the test. The subject then executed three maximal extensions at 180 degrees/sec. The highest peak torque value was measured and recorded (Clarkson et al., 1982; Gilliam et al., 1979; Housh et al., 1984; Haymes & Dickinson, 1980).

Grip Strength

Grip strength was determined using the Jumar adjustable grip dynamometer. The dynamometer was adjusted to the hand size of the subject (Lamphier & Montoye, 1976). The subjects stood with their shoulder adducted and neutrally rotated, elbow flexed at approximately 90 degrees, forearm in a neutral position, and wrist between approximately 0 - 30 degrees dorsiflexion and 0 - 15 degrees ulnar deviation (Mathiowetz et al., 1985). Three trails were administered to the dominant hand (determined by throwing preference) with a 1 - 1 1/2 minute rest period between trials (Lamphier &

Montoye, 1976). Measurements were recorded to the nearest 0.1 kg and the highest value was used.

Anaerobic Work Indices

Anaerobic power, anaerobic capacity, and fatigue index were measured using the Wingate Anaerobic Test (WAnT). Upper and lower body anaerobic work indices were measured simultaneously on a 650 Monark bicycle and a Monark arm ergometer. Prior to the start of each test, the seat of the bicycle ergometer was adjusted so that the subject's legs were near full extension when pedaling. The axis of the crank arm on the arm ergometer was aligned with the subject's glenohumeral joint (Reybrouck et al., 1975; Seals & Mullin, 1982). The test was preceded by a standardized warm-up, which was 4 minutes of slow pedaling against zero resistance interspersed with two to three sprints of 4 to 5 seconds duration (Bar-Or, 1978; Inbar & Bar-Or, 1975).
After the warm-up the subject rested for about 2 minutes during which time the procedures for the WAnT were reviewed. At the command "Go" the subject began pedaling as fast as possible while the researchers increased the resistance to 0.05 and 0.06 X BW (kg), for arms and legs, respectively, within the first 2 to 3 seconds (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). As soon as the work load was set, the 30 second test was begun during which the subject was encouraged to give a maximal effort. The

workload and elapsed time were carefully monitored throughout the time period. A 2 to 4 minute cool-down followed the test to prevent dizziness and muscle soreness (Thorland, Johnson, Cisar, Housh & Tharp, 1987). Anaerobic power was calculated as the highest kgm/5-sec work interval and anaerobic capacity as the total kgm/30-sec work interval (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). Fatigue index was calculated as the highest 5-sec peak power minus the lowest 5-sec peak power, divided by the highest peak power, multiplied by 100 (Bar-Or, 1978). All values reflected the combined arm and leg (A&L) anaerobic power, capacity, and fatigue index.

Body Composition

Body composition was determined by underwater weighing with correction made for residual lung volume using the helium dilution method. The residual lung volume, as measured with a Collins RS Unit, was an average of two trials (*Systems manual for Collins residual volume, pulmonary function testing system*, 1983). Body weight in kg was measured on a platform scale for all subjects. Underwater weighing was performed in a metal tank in which a webbed sling was suspended from a Chatillon Scale. Subjects performed six to ten trails of underwater weighing with the average of the three scores, which were $\pm$ 0.05 kg of each other, used to represent the underwater weight (Cisar et al., 1986). Relative fat was calculated from the formula of Brozek et al. (1963) and LBW was calculated from the values for BW and RF.

Anthropometry

Body build characteristics were determined by obtaining anthropometric measurements and height. Height was measured using a wall scale with a Broca plane. Lange calipers were used to measure skinfold thickness at triceps, subscapular, supra-iliac, and calf sites (Behnke & Wilmore, 1974). The average of at least two repeated trails, within 0.5 mm of each other, were used as the representative score (Cisar et al., 1987).

Biacromical and bi-iliac diameters of the elbow and the knee, were measured with a broad blade anthropometer to the nearest 0.1 cm. Circumferences of the flexed arm and calf were measured, with Lufkin metal tape fitted with a Gullick handle, to the nearest 0.1 cm. Anthropometric sites used are those described by Behnke and Wilmore (1974). These measurements were used to calculate body somatotypes using anthropometric rating methods as described by Heath and Carter (1967). The three-component somatotype rating (endomorphy, mesomorphy, and ectomorphy) were converted to bidimensional scores, X and Y, as described by Ross and Wilson (1973).

Aerobic Capacity Test

Aerobic capacity was tested using a combined arm and leg cranking task on a Monark 650 bicycle ergometer and a Monark arm ergometer. Subjects were fitted with headgear which supported a Hans-Rudolph respiratory value and a mouth piece. Inhaled air passed through a Parkinson-Cowan CD-4 Dry Test meter and then into the respiratory value. A potentiometer which was connected to a Gilson recorder, model 5-6H, was used to record the volume of inspired air. Expired air passed out of the Hans-Rudolph value into a mixing chamber.

A Wilmore-Costill Spinner Value (WCSV) system was used to collect expired air so as to be able to analyze the oxygen (FeO2) and carbon dioxide (FeCO2) content of the air sample. The sample of expired gases passed through the mixing chamber into the WCSV system before passing into the analyzers. A Beckman LB-2 Medical Gas Analyzer was used for percent carbon dioxide, and a Applied Electrochemical S-3A analyzer determined the percent oxygen. The analyzers were calibrated before each test and during every stage (3 minutes) of the test with a standard gas sample. Data for inspired and expired air was collected every minute of the test. Heart rate was monitored on a Quinton 623A electrocardiogram (ECG) monitoring system. The ECG was printed out for the last 10 seconds of every minute of the test at the speed of 25m/sec.

The ECG monitor was used to observe the electrical patterns of the subject's heart throughout the test and to obtain heart rate. Six surface electrodes (right and left arm, right and left leg, sternum, and V5) were used to monitor the electrical patterns of the subject's heart.

The subject began the test seated on the bicycle ergometer with the seat height adjusted so that there was near full leg extension. The axis of the crank arm of the arm ergometer was then aligned with the subject's glenohumeral joint (Reybrouck et al., 1975; Seals & Mullin, 1982). Every three minutes the resistance was increased by 1.0 kp (0.25 kp arms and 0.75 kp legs) until voluntary exhaustion. A metronome was used to set pedaling cadence while a Gralab clock was used to maintain the time interval. Exhaustion was defined as a failure by the subject to maintain the required 60 rpm (Seals & Mullin, 1982). Failure to maintain rpm was determined by the person setting resistance. The person setting resistance monitored the subject's rate of leg pedaling with a metronome (set at 120) and the rate of arms cranking with the rpm monitor. The test was terminated if any of the following situations occurred during the test: (1) a signal from the subject that he wished to stop the test, (2) failure of heart rate to increase with increasing work loads, (3) pain or fatigue as indicated by decreasing coordination or pallor, (4) failure to maintain cadence at 60 rpm, (5) any abnormalities on the ECG reading, or (6) equipment failure (ACSM, 1986).

A cool-down period followed the maximal oxygen test, until the subject's heart rate decreased to/or below 120 bpm. A post exercise ECG strip was obtained prior to the removal of the electrodes. Atmospheric readings (temperature and barometric pressure and humidity) were obtained at the end of each test.

Expired ventilation (VE) was calculated from the inspired ventilation rate (VI). Oxygen consumption (VO2) and carbon dioxide production (VCO2) rates were calculated from VI, VE, FEO2, and FECO2 values.

Analysis of Data

Descriptive statistics (*M*, *SD*, and range) were used to describe the characteristics for all of the subjects and the Pearson product-moment correlations were used to examine the relationship between descriptive characteristics. One-way analysis of variance and Tukey post-hoc tests were used to examine the mean differences in the descriptive characteristics of the subjects across climbing groups. Full-model and stepwise multiple regression were used to examine the relationship of the physiological variables to the climber rating. Multiple discriminant analysis was used to determine which variables discriminated between the climbing ability of the elite, intermediate, and novice climbers. In addition Pearson product-moment correlations were used to examine the intercorrelations between the selected physiological variables and the climber rating. The computer program SPSSx (SPSSx User's Guide, 1983) was used for statistical analysis of data.

CHAPTER IV

Analysis of Data

Level of Significance

A probability level (*p*) of .05 or less was selected as the level of statistical significance for all the analysis of data.

Analysis of Data

Forty-one healthy male subjects were tested in the study. However, one subject's data was not used as there was no accurate residual lung volume obtained on this subject. Table 5 summarizes the descriptive characteristics for all of the subjects. Table 6 summarizes the descriptive characteristics of the subjects by groups and the results of the one-way analysis of variances and Tukey post-hoc tests used to examine the mean differences in the descriptive characteristics of the subjects across ranked groups. There were no significant differences between groups in age, hgt, BW, LBW, leg strength, ventilatory threshold, arm strength, A & L anaerobic power, A & L anaerobic capacity, A & L fatigue index , X rating, and Y rating. Although there were no significant ($p \leq .05$) differences between elite, intermediate, and novice climbers on the above mentioned variables, the elite climbers tended to be lower in X (linearity - fatness) and higher on Y (muscularity), lean body weight, and arm strength. There were significant

Table 5

Descriptive Characteristics of the Subjects

n = 40	Mean	Range	SD
Age (yr)	26.68	20.75	5.23
Height (cm)	178.03	37.70	8.39
Body weight (kg)	71.47	50.65	9.41
Relative fat (%)	13.97	25.50	5.48
Fat weight (kg)	10.16	26.86	4.93
Lean body weight (kg)	61.31	35.31	7.66
Leg strength (ft/lbs)	102.15	67.00	15.86
Shoulder strength (ft/lbs)	53.35	39.00	9.21
Arm strength (ft/lbs)	39.40	42.00	9.24
Grip strength (kg)	52.24	36.50	8.84
Anaerobic power (kgm/5sec)	453.20	348.70	68.05
Anaerobic capacity (kgm/30sec)	2085.24	1644.00	311.15
Fatigue index (%)	43.50	32.00	6.03
Ventilatory threshold (l/min)	2.23	1.53	0.37
Maximal oxygen uptake (l/min)	3.25	2.31	0.51
X rating	-0.42	9.57	2.19
Y rating	1.41	11.52	2.63

Table 6

Descriptive Characteristics of the Subjects Across Climbing Groups

	Groups		
Characteristics	Elite	Intermediate	Novice
n	8	20	12
Age (yr)	29.01$\pm$ 1.49	29.52$\pm$ 1.08	30.40$\pm$ 1.93
Body weight/ (kg)	72.13$\pm$ 1.85	70.04$\pm$ 2.34	73.42$\pm$ 2.88
Relative fat/ (%) ***	12.41$\pm$ 1.50	12.51$\pm$ 0.89	17.44$\pm$ 2.02
Fat weight/ (kg) ***	9.09$\pm$ 1.22	8.84$\pm$ 0.75	13.09$\pm$ 2.00
Lean body/ weight (kg)	63.04$\pm$ 1.24	61.20$\pm$ 2.03	60.33$\pm$ 2.13
Leg strength/ (ft/lbs)	97.86$\pm$ 4.86	104.35$\pm$ 3.90	101.33$\pm$ 4.30

Value are $M \pm$ SEM.

*** One-way analysis of variance significant at $p \leq .05$ and Tukey post-hoc difference between intermediate and novice groups.

Table 6

Descriptive Characteristics of the Subjects Across Climbing Groups (continued)

	Groups		
Characteristics	Elite	Intermediate	Novice
n	8	20	12
Shoulder strength/ (ft/lbs) **	58.38± 2.04	55.30± 2.89	46.75± 2.17
Arm strength/ (ft/lbs)	40.75± 1.41	38.60± 1.66	39.83± 4.03
Grip strength/ (kg) *	59.19± 3.18	52.75± 1.96	46.75± 1.43
A&L anaerobic power/ (kgm/5sec)	453.94± 10.7	455.15± 19.5	449.46± 14.9
A&L anaerobic capacity/ (kgm/30sec)	1995.8± 111.5	2123.6± 81.9	2080.0± 57.6

Values are $M \pm$ SEM.

** One-way analysis of variance significant at $p \leq .05$ and Tukey post-hoc difference between elite and novice groups and intermediate and novice groups.

* One-way analysis of variance significant at $p \leq .05$ and Tukey post-hoc differences between elite and novice groups.

Table 6

Descriptive Characteristics of the Subjects Across Climbing Groups (continued)

	Groups		
Characteristics	Elite	Intermediate	Novice
n	8	20	12
Fatigue index/ (%)	44.06 ± 2.72	43.30 ± 1.11	43.46 ± 2.00
Ventilatory threshold/ (l/min)	2.15 ± 0.11	2.20 ± 0.09	2.34 ± 0.10
Maximal oxygen/ uptake (l/min)	3.17 ± 0.11	3.32 ± 0.15	3.19 ± 0.09
X rating	-0.44 ± 0.58	0.23 ± 0.47	-1.50 ± 0.73
Y rating	2.63 ± 0.58	1.23 ± 0.66	0.90 ± 0.73

Values equal *M* ± SEM.

differences between intermediate and beginning climbers on relative fat, fat weight, and shoulder strength. In addition there were significant differences between elite and beginning climbers in shoulder strength and grip strength. It was noted that elite climbers tended to have higher grip strength than intermediate climber as well.

Table 7 presents the zero-order correlation matrix between the descriptive characteristics for the overall group of subjects. The intercorrelation coefficients between the predictor variables exhibited a wide range of values ($\underline{r}$ = .00 to .89). Those variables that had significant correlations with climbing rating were RF, FW, AS, GS, A&L anaerobic power, and X rating.

Table 8 summarizes the full-model and the stepwise multiple regression analysis for the prediction of climbing ability from the variables measured for all groups of subjects. The full-model analysis resulted in a $\underline{F}$ = 2.61, $\underline{R}$ = .77, $\underline{SEE}$ = .019, while the stepwise multiple regression analysis resulted in a $\underline{F}$ = 9.94, $\underline{R}$ = .67, $\underline{SEE}$ = .018. The stepwise multiple regression analysis also identified shoulder strength, body weight, and grip strength as the significant variables in the model. These three variables (SS, BW, GS) accounted for 45.3% of the variance in climbing ability (ranking). Of the variables selected in the stepwise multiple regression analysis, shoulder strength accounted for

Table 7
Zero-order Correlation Matrix for the Descriptive Characteristics of the Subjects
(n = 40)

	BW	RF	FW	LBW	LS	AS	SS	GS	ALAP	ALAC	FI	ANT	VO2MX	X	Y	CR
Body Weight (BW)	1.00															
Relative Fat (RF)	.36	1.00														
Fat Weight (FW)	.58	.96	1.00													
Lean Body Weight (LBW)	.86	-.17	.07	1.00												
Leg Strength (LS)	.70	.08	.23	.71	1.00											
Shoulder Strength (SS)	.40	-.12	.02	.47	.30	1.00										
Arm Strength (AS)	.58	-.17	.04	.70	.63	.21	1.00									
Grip Strength (GS)	.48	-.14	.01	.88	.45	.60	.32	1.00								
Anaerobic Power (ALAP)	.80	-.07	.13	.89	.72	.50	.86	.50	1.00							
Anaerobic Capacity (ALAC)	.84	-.17	.01	.78	.67	.42	.80	.37	.80	1.00						
Fatigue Index (FI)	.21	.08	.10	.19	.30	.08	.20	.18	.37	-.01	1.00					
Ventilatory Threshold (VT)	.34	.08	.17	.31	.09	.22	.25	.18	.37	.24	.16	1.00				
Maximal O2 uptake (VO2MX)	.43	-.17	.04	.55	.38	.35	.36	.27	.54	.52	-.08	.62	1.00			
X Rating (X)	-.53	-.73	-.78	-.15	-.31	-.07	-.18	-.07	-.24	-.10	-.12	-.10	- .11	1.00		
Y Rating (Y)	-.04	-.15	-.10	.12	.09	.40	.29	.28	.11	.14	-.19	.09	.31	-.34	1.00	
Climber Rating (CR)	-.02	-.37	-.38	.01	-.10	.42	-.10	.41	-.70	-.07	-.04	-.22	.08	.32	.17	1.00

Note. r ≥ ± .31 required for significance at p ≤ .05.

Table 8

Full-model and Stepwise Multiple Regression and Beta Coefficient Analysis for the Prediction of Climbing Ability (n = 40)

Predictor Variable	Full-Model* Regression coefficient	Beta coefficient	Stepwise** R	Stepwise** F
1. Shoulder strength (ft/lbs)	.0011	0.44	.42	8.17**
2. Body weight (kg)	-.0018	-0.73	.58	9.43**
3. Grip strength (kg)	.0012	0.44	.67	9.94**
4. Ventilatory threshold (l/min)	-.0308	-0.48	.70	8.45
5. Maximal oxygen uptake (l/min)	.0219	0.47	.73	7.62
6. Leg strength (ft/lbs)	-.0004	-0.25	.74	6.64
7. Y rating	-.0012	-0.13	.75	5.88
8. Anaerobic capacity (kgm/30sec)	-.00001	-0.08	.76	5.15
9. Arm strength (ft/lbs)	.0003	0.13	.76	4.61
10. Fatigue index (%)	.0006	0.15	.76	4.06
11. Anaerobic power (kgm/5sec)	-.0001	-0.30	.77	3.65
12. X rating	.0007	0.07	.77	3.27
13. Lean body weight (kg)	.0015	0.49	.77	2.91
14. Relative fat (%)	.0009	0.22	.77	2.61
(Constant)	5.0511			

* $p \leq .05$; R = .77, SEE = .019, * F = 2.61

** $p \leq .05$; R = .67, SEE = .018, ** F = 9.94

Note. Climbing ability = 5.0769 + SS(.00097) - BW(.00142) + GS(.00120).

17.7% of the variance between groups, with an additional 16.1% of the variance accounted for by body weight and 11.5% by grip strength. The addition of the remaining variables accounted for an additional 14.0% of the variance in climbing rating (ranking). The following prediction formula was developed by stepwise multiple regession analysis: climbing ability = 5.0769 + SS(.00097) - BW(.00142) + GS(.00120).

Table 9 shows the rotated discriminant function coefficients for each discriminant function. These functions represent the relative importance of each predictor variable to the discriminant function. Discriminant function one (DF1), comprised of grip strength and anaerobic work indices, accounted for 62.5% of the variance between groups while discriminant function two (DF2), physical development indices, accounted for the remaining 37.6% of the variance.

Table 10 summarizes the discriminant functions as evaluated by group centroids (means). Discriminant function 1 tended to discriminate between the elite versus the novice climber (-.9661 vs. .9174), whereas DF2 tended to discriminate between the intermediate and the novice climbers (-.5124 vs .9877). Grip strength, A&L anaerobic capacity, X rating, A&L anaerobic power, A&L fatigue index, and ventilatory threshold tended to be most highly related to DF1. The other variables (body weight, Y rating, fat weight,

Table 9

Rotated Discriminant Matrix for Prediction of Climbing Ability

Variable	Function 1	Function 2
Grip strength (kg)	-0.852a	-0.182
Anaerobic capacity (kgm/30sec)	0.676a	-0.146
Ventilatory threshold (l/min)	0.664a	0.581
X rating	0.446a	-0.265
Anaerobic power (kgm/5sec)	0.371a	-0.331
Fatigue index (%)	-0.167a	-0.025
Fat weight (kg)	0.127	-3.465b
Relative fat (%)	0.650	2.768b
Body weight (kg)	-0.476	2.461b
Leg strength (ft/lbs)	0.855	-0.909b
Maximal oxygen uptake (l/min)	-0.255	-0.775b
Shoulder strength (ft/lbs)	-0.597	-0.605b
Arm strength (ft/lbs)	-0.430	0.478b
Y rating	0.223	0.472b

a Denotes discrimination function with which predictor variable, discriminant function 1, was most highly related.
b Denotes discrimination function with which predictor variable, discriminant function 2, was most highly related.

Table 10

Discriminant Functions Evaluated by Centroids (means)

Group	Function 1	Function 2
Elite	-.966	-.201
Intermediate	-.164	-.512
Novice	.917	.988

relative fat, maximal oxygen uptake, leg strength, arm strength, and shoulder strength) were most highly related to DF2.

Table 11 illustrates the classification results developed from the multiple discriminant analysis. There was excellent classification of intermediate climbers, moderate classification of novice climbers, and a poor classification of elite climbers. The percentage of the total "grouped" cases correctly classified was 67.5%.

Summary of Findings

There were no significant differences observed in the descriptive characteristics of the subjects across the rating (ranking) groups for body weight, lean body weight, leg strength, arm strength, anaerobic power, anaerobic capacity, fatigue index, ventilatory threshold, maximal oxygen uptake, X rating, and Y rating. There were significant differences noted between intermediate and novice groups in relative fat, fat weight, and shoulder strength. There were also significant differences noted between elite and novice groups in shoulder strength and grip strength. The stepwise multiple regression analysis identified shoulder strength, body weight, and grip strength as significant variables in the modeling, accounting for 17.7%, 16.1%, and 11.5% of the variance between groups, respectively. Multiple discriminant analysis identified two functions best described as a grip

Table 11

Group Classification Results of Multiple Discriminant Analysis

		Predicted Group Membership		
Actual Group	*n*	Elite	Intermediate	Novice
Elite	8	2	6	0
		(25.0%)	(75.0%)	(00.0%)
Intermediate	20	0	18	2
		(00.0%)	(90.0%)	(10.0%)
Novice	12	0	5	7
		(00.0%)	(41.7%)	(58.3%)

Note. Correct classification of 67.5%.

strength/anaerobic function (DF1) and physical development function (DF2). Discrimimant function 1 accounted for 62.5% of the variance between groups and DF2 accounted for the remaining 37.6% variance between groups. The discriminant analysis correctly classified 67.5% of the climbers. The breakdown between groups indicated that only 25% of elite group were classified correctly, 58.3% of novice group were classified correctly, while 90% of intermediate group were classified correctly. The classification equation developed from the discriminant analysis appears to do an excellent job of classification for the intermediate level climbers.

Discussion of Findings

The primary purpose of this study was to investigate the physiological determinants of rock climbing ability. It appears that for this group of 40 climbers who were tested, most of the variance between groups was due to grip strength/anaerobic function. The physical development function accounted for a smaller percentage of the variance (37.6%). Stepwise multiple regression analysis indicated that 45.3% of the variance between groups was accounted for by shoulder strength, body weight, and grip strength.

Climbers, in this study, when compared to other upper body athletes and high altitude climbers, had a lower aerobic capacity as measured by VO2 max and a higher relative fat percentage (Oelz et al., 1986; Puhl et al., 1982; Tesch, 1983; Vaccaro et al., 1984). In the review of literature on upper body athletes most athletes tested were elite level athletes, but even when only the elite climbers in this study were compared, they still had a much lower aerobic capacity and higher relative fat. This suggested that aerobic capacity is not as important a factor in climbing performance as it is for other upper body athletes, possibly because of rock climbing's discontinuous nature.

In looking at body typing the elite climbers were more mesomorphic (4.37 $\pm$ 0.23). Vaccaro et al. (1984) found that elite paddlers were also more mesomorphic. Elite gymnasts had an even higher mesomorphic rating (6.4) (Cater et al., 1971). Wrestlers studied by Cisar et al. (1987) had a mesomorphic rating (4.49 $\pm$ 0.88) similar to the elite climbing group. However in somatotype ratings (X & Y) the wrestlers had higher muscularity scores and lower linearity - fatness scores than the elite climbers in this study.

When comparing climbers to wrestlers it was noted that wrestlers had similar height and body weight to climbers, but lower relative fat and higher lean body weight and maximal oxygen uptake (Kelly et al., 1978). When the elite group of climbers were compared to the elite wrestlers in Gale and Flynn's study (1974) descriptive measurements of height, body weight, and age, were similar to rock climbers, but wrestlers had higher lean body weight and maximal oxygen uptake.

In this study the two discriminant functions were not as evenly weighted and the function variables differed then those found by Cisar et al. (1987). Whereas Cisar et al. (1987) had poor prediction for the intermediate level wrestlers, in this study the intermediate climbers had excellent prediction but there was poor prediction for the elite. These results suggest that discrimination between elite and intermediate climbers may be explained by additional variables not measured, such as psychological factors and technical skill. Novice climbers had moderate prediction rates while novice wrestlers in Cisar's study had good prediction.

When looking at strength measures climbers had greater leg strength and arm strength than did wrestlers (Cisar et al., 1987). However, the wrestlers were smaller and younger than the climbers tested. The climbers also had greater leg, shoulder, and arm strength than the elite volleyball players tested by Puhl (1982). The ages were similar between the two groups, but the volleyball players were larger and heavier than the climbers.

When results of aerobic measures were compared to other studies using similar methodology (arm and leg cranking) for measurement of VO2 max, the values obtained for the climbers were similar to those measured by Glesser et al. (1974).

However, the values of the climbers were much lower than those obtained on well trained upper body athletes measured by Seals and Mullin (1982).

One measure, grip strength, was not measured in other profiling studies. So results were compared to normal population averages measured by Mathiowetz et al. (1985). The mean value for climbers fell within the normal range of men between the ages of 20 to 39 years of age; however, elite climbers were above normal range in grip strength when compared to the population averages.

Conclusions

Within the limits of this study the following conclusions were made:

(1) the descriptive characteristics of the overall group of climbers were similar and differed only on relative fat, fat weight, shoulder strength, and grip strength.

(2) stepwise regression identified three variables as accounting for 45.3% of the variance between climbers: shoulder strength, body weight, and grip strength. Other variables measured accounted for an additional 14.0% of variance in climbing ability.

(3) the discriminant function 1 (grip strength, arm and leg anaerobic power, arm and leg anaerobic capacity, ventilatory threshold, X rating, and arm and leg fatigue index) accounted for 62.45% of the variance between groups.

Discriminant function 2 (fat weight, relative fat, body weight, leg strength, maximal oxygen uptake, shoulder strength, arm strength, and Y rating) accounted for the remaining 37.55% of the variance between groups.

Weaknesses

All groups did not contain 14 subjects which may have affected results found with multiple discriminant analysis as it is recommended that at least one subject per variable be included in each group. Volunteers subjects made it difficult to draw elite level climbers into the study. In dividing subjects into groups, eight subjects fell between groups (i.e., Lead 5.10-5.11). This may have also affected the results of the statistical analysis, especially the multiple discriminant analysis. It appears more refinement in group placement was needed. An additional weakness was the subjective assessment of subject's climbing ability; it appeared that in some cases the subject's self rating may have been higher than actual climbing ability (at time of testing). Also motivation, training status, and inexperience with testing techniques may have played a role in testing results.

In addition, the small number of elite climbers may have affected the results of one-way analysis of variance. There may have been some additional statistically significant differences between groups which were not apparent due to the small group size of the elite group.

Recommendations for Future Research

Within the limits of this study the following recommendations are made:

(1) Future research should examine the relationship of psychological variables to climbing ability as well as the physiological variables.

(2) Future research should examine other variables such as flexibility, anaerobic indices of only the upper body, strength to weight ratio, upper body strength at 30 and 60 degrees per second, and additional measures of finger/hand strength and endurance to see if these may account for additional variance between groups.

(3) Lactic acid levels should be examined to see if there is any relationship of lactic acid tolerance to climbing ability.

(4) Future research should examine the relationship of technical skill to climbing ability.

(5) It is suggested that more data be collected on the same physiological variables on elite competitive climbers as this would add additional information to the data collected in this study.

(6) Future research should examine the physiological determinants of climbing performance in female subjects.

(7) Future research should attempt to cross-validate the existing climbing performance prediction models on other samples of subjects in order to determine the validity of this model.

CHAPTER V

Summary

Introduction

Review of literature has indicated that physiological profile studies can be used to identify characteristics which make for successful athletic performances. A profile study was undertaken on rock climbers to identify the variables that separate the elite from the intermediate and/or novice climbers and to establish which physiological characteristics are important in rock climbing.

Summary

Subjects for this investigation included 40 active male rock climbers, between the ages of 20 to 40 years. Based upon self reported lead capability, the climbers were divided into three groups: novice, intermediate, and elite. There were 12 novice climbers, 20 intermediate, and 8 elite climbers. If a subject fell between groups the climber was placed in the higher level group.

Lab testing involved measurements of arm, shoulder, leg, and grip strength, anaerobic power, anaerobic capacity, and fatigue index, anthropometric measurements, body composition, and aerobic metabolic response. Arm, shoulder, and leg strength were measured using an isokinetic Cybex II+ dynamometer. Anaerobic power, anaerobic capacity, and fatigue index were measured using combined arms and legs on the Wingate test. Body size and composition measures included body weight, relative fat, fat weight, and lean body weight. Body composition was determined by underwater weighing corrected for residual lung volume. Body build measurements included a X rating (muscularity) and a Y rating (linearity - fatness) which were determined from anthropometric measurements. Ventilatory threshold and maximal oxygen uptake were determined from analysis of expired gas percentages and volumes during each minute of a graded, combined arm and leg, cranking task to voluntary exhaustion.

Descriptive statistics were used to describe physiological characteristics of all climbers. The group differences between the elite, intermediate, and novice climbers were assessed using a one-way analysis of variance for each variable with Tukey post-hoc tests used as a follow-up to identify mean specific differences in the descriptive variables between climbing groups. In addition the Pearson product-moment correlations were used to examine the intercorrelation between selected physiological variables.

Full-model and stepwise multiple regression were used to examine the relationship of physiological variables to climber rating for all groups of subjects. Multiple discriminant analysis was used to determine which variables discriminated between the climbing ability of the groups.

The results of this study showed that shoulder strength, body weight, and grip strength accounted for 45.3% of the variance between groups. The remaining 14.0% variance was explained by the remaining 11 variables measured. This indicated that 40.7% of the variance between groups was explained by variables not measured. Multiple discriminant analysis indicated two functions, DF1 which accounted for 62.5% of the variance between groups and DF2 which accounted for the remaining 37.6% of the variance between groups. Discriminant function 1 was best described as a grip strength/anaerobic function, while discriminant function 2 was mainly described as a physical development function. Discriminant analysis correctly classified 67.5% of the climbers. The discriminant analysis appeared to do an excellent job of classifying the intermediate level climber.

Conclusion

The descriptive characteristics of groups were not significantly different on body weight, lean body weight, leg strength, arm strength, arm and leg anaerobic power, arm and leg anaerobic capacity, fatigue index, ventilatory threshold, maximal oxygen uptake, X rating, and Y rating, but did significantly differ on relative fat, fat weight, shoulder strength, and grip strength. Three variables were identified as accounting for 45.3% of the variance between groups: shoulder strength, body weight, and grip strength. The discriminant analysis correctly classified 67.5% of the rock climbers. It is suggested that further research should be done to cross validate the existing climbing performance prediction models on other samples of subjects.

Within the limitations of this study the following recommendations are made:

(1) climbers should increase shoulder and grip strength as well as reducing body weight to improve performance.

(2) anaerobic work function accounted for much of the variance between groups suggesting that in training climbers should increase anaerobic power, anaerobic capacity, and fatigue index with weight training and interval boulder training.

(3) grip strength function also accounted for variance between groups indicating finger and hand strength should be emphasized.

(4) climbers should increase technical skill and practice psychological training techniques (imagery, biofeed back, and relaxation techniques) to improve performance as 40.7% of the variance was between groups was unaccounted for by physiological variables.

References

American College of Sports Medicine (1986). Guidelines for exercise testing and prescription. Philadelphia: Lea & Febiger.

Astrand, P. O., & Rodahl, K. (1987). Textbook of work physiology: Physiological basis of exercise. New York: McGraw-Hill.

Bar-Or, O. (1978). A new anaerobic capacity test -- characteristics and application. Paper presented at the 21st World Congress in Sports Medicine, Brasilia.

Bar-Or, O. (1983). Pediatric sports medicine for the practitioner from physiologic principles to clinical application. New York: Springer-Verlag.

Baker, S. J. (1980). An intensive alpine climbing expedition and its influence on some anthropometric measurements. British Journal of Sports Medicine, 14, 126-130.

Behnke, A. R., & Wilmore J. H. (1974). Evaluation and regulation of body build and composition. Englewood Cliffs, N. J.: Prentice Hall.

Bergh, U., Kanstrup, L., & Ekblom, B. (1976). Maximal oxygen uptake during exercise with various combinations of arm and leg work. Journal of Applied Physiology, 41, 191-196.

Brozek, J. F., Grande, J. T., Anderson, J., & Keys, A. (1963). Densiometric analysis of body composition: Revision of some quantitative assumptions. Annals of the New York Academy of Science, 110, 113-140.

Cisar, C. J., Johnson, G. O., Fry, A. C., Housh, T. J., Hughes, R. A., Ryan, A. J., & Thorland, W. G. (1987). Preseason body composition, build, and strength as predictors of high school wrestling success. Journal of Applied Sports Science Research, 4, 166-170.

Clarkson, P. M., Johnson, J., Dextradeur, D., Lezcyski, W., Wai, J., & Melchionda, A. (1982). Relationship between isokinetic endurance, initial strength levels, and fiber. Research Quarterly, 53, 15-19.

Daniels, J. (1978). Physiological characteristics of champion male athletes. Research Quarterly, 49, 342-348.

Dwyer, J. (1983). Marathon swimmers: Physiologic characteristics. Journal of Sports Medicine, 23, 263-277.

Fox, E. L., & Mathews, D. K. (1981). The physiological basis of physical education and athletics (3rd ed.). Philadelphia: Saunders.

Gale, J. B., & Flynn, K. W. (1974). Maximal oxygen consumption and relative body fat of high-ability wrestlers. Medicine and Science in Sports and Exercise, 6, 232-234.

Gilliam, T. B., Villancci, J. F., Freedson, P. S., & Sady, S. P. (1979). Isokinetic torque in boys and girls ages 7 to 13: effect of age, height, and weight. Research Quarterly, 50, 599-609.

Haymes, E. M., & Dickerson, A. L. (1980). Characteristics of elite male and female ski racers. Medicine and Science in Sports and Exercise, 12, 153-158.

Heath, B. H., & Carter, J. E. L. (1967). A modified somatotype method. American Journal of Physiological Anthropology, 27, 57-74.

Housh, T. J., Thorland, W. G., Johnson, G. O., Tharp, G. D., Cisar, C. J., Refsell, M. J., & Ansorge, C. J. (1984). Body composition variables as discriminators of sports participation of elite adolescent female athletes. Research Quarterly for Exercise and Sport, 55, 302-304.

Inbar, O., & Bar-Or, O. (1975). The effects of intermittent warm-up on 7 - 9 year old boys. European Journal of Applied Physiology, 34, 81-89.

Inbar, O., Kaiser, P., Dotan, R., Bar-Or, O., Schele, R., & Karlson, J. (1979). Indices of the Wingate anaerobic test, fiber-type distribution and running performance in men. Medicine and Science in Sports and Exercise, 11, 29.

Isolated - joint testing & exercise: A handbook for using Cybex II+ and U.B.X.T. (1983). Bayshore, N. Y. : Lumax.

Jackson, A. A., (1984). Research design and analysis of data procedures for predicting body density. Medicine and Science in Sports and Exercise, 16, 616-620.

Kelly, J. M., Gorney, B. A., & Kalm, K. K. (1978). The effects of a collegiate wrestling season on body composition, cardiovascular fitness and muscular strength and endurance. Medicine and Science in Sports and Exercise, 10, 119-124.

Kohrt, W. M., Morgan, D. W., Bates, B., & Skinner, J. S. (1987). Physiological responses of triathletes to maximal swimming, cycling and running. Medicine and Science in Sports and Exercise, 19, 51-55.

Lamb, D. R. (1984). Physiology of exercise (2nd ed.). New York: MacMillan.

Lamphier, D. E., & Montoye, H. J. (1976). Muscular strength and body size. Human Biology, 48, 147-160.

Loughman, M. (1981). Learning to rock climb. San Fransisco: Sierra Club Books.

Mathiowetz, V., Kashman, N., Volland, G., Weber, K., Dowe, M., & Rogers, S. (1985). Grip and pinch strength: Normative data for adults. Archives of Physical Medicine Rehabilitation, 66, 69-72.

Nicholas, J. A. (1984). The value of sports profiling. Clinics in Sports Medicine, 3 (1), 3-10.

Oelz, O., Howard, H., DePrampero, P. E., Hoppeler, H., Claassen, H., Jenni, R., Buhlemann, A., Gussoni, M., & Cerretelli, P. (1986). Physiological profile of world-class high altitude climbers. Journal of Applied Physiology, 60, 1734-1742.

O'Toole, M. L., Hiller, W. D. B., Crosby, L. O., & Douglas, P. S. (1987). The ultraendurance triathlete: A physiological profile. Medicine and Science in Sports and Exercise, 19, 45-50.

Puhl, J., Case, S., Fleck, S., & Van Handel, P. (1982). Physical and physiological characteristics of elite volleyball players. Research Quarterly for Exercise and Sport, 53, 58-63.

Reybrouck, T., Heigenhauser, G. F., & Faulkner, J. A. (1975). Limitation to maximal oxygen uptake in arm, leg, and combined arm-leg ergometry. Journal of Applied Physiology, 38 (5), 774-779.

Ross, W. D., & Wilson, B. D. (1973). A somatotype dispersion index. Research Quarterly, 44, 372-374.

Ross, W. D., & Wilson, B. D. (1967). Maximal oxygen uptake in athletes. Journal of Applied Physiology, 23 (3), 353-358.

Seals, D. R., & Mullin, J. P. (1982). VO2 max in variable type exercise among well-trained upper body athletes. Research Quarterly for Exercise and Sport, 53, 58-63.

SPSSx user's guide (1983). New York: McGraw Hill.

Stromme, S. D., Ingjer, F., & Meen, H. D. (1977). Assessment of maximal aerobic power in specifically trained athletes. Journal of Applied Physiology, 42, 833-837.

Systems manual for Collins residual volume, pulmonary function testing system (1983).

Tesch, P. A. (1983). Physiological characteristics of elite kayak paddlers. Canadian Journal of Applied Sport and Science, 8, 87-91.

Tharp, G. D., Newhouse, R. K., Uffelman, L., Thorland, W. G., & Johnson, G. O. (1985). Comparison of sprint and run times with performance on the Wingate Anaerobic Test. Research Quarterly for Exercise and Sports, 56, 73-76.

Tharp, G. D., Johnson, G. O., & Thorland, W. G. (1984). Measurement of anaerobic power and capacity in elite young track athletes using the Wingate test. Journal of Sports Medicine and Physical Fitness, 24, 100-106.

Thorland, W. G., Johnson, G. O., Cisar, C. J., Housh, T. J., & Tharp, G. D. (1987). Strength and anaerobic response of elite young female sprint and distance runners. Medicine and Science in Sport and Exercise, 19, 56-61.

Vaccaro, P., Gray, P. R., Clarke, D. H., & Morris, A. F. (1984). Physiological characteristics of world class white-water slalom paddlers. Research Quarterly for Sports and Exercise, 55, 206-210.

Wasserman, K., Whipp, B., Koyal, S., & Beaver, W. L. (1973). Anaerobic threshold and respiratory gas exchange during exercise. Journal of Applied Physiology, 35, 236-243.

Appendix A

STUDY TO INVESTIGATE THE PHYSIOLOGICAL CHARACTERISTICS OF ROCK CLIMBERS

STATEMENT OF INFORMED CONSENT -- FOR MUSCULAR STRENGTH, GRIP STRENGTH, ANAEROBIC CAPACITY, BODY COMPOSITION AND SIZE, AND CARDIORESPIRATORY ENDURANCE

Invitation to Participate

You are invited to participate in a study investigating the effects of muscular strength, grip strength, anaerobic work indices, body composition and size, and cardiorespiratory (heart-lung function) endurance characteristics on rock climbing performance. This study will be conducted at the San Jose State University campus.

Basis for selection

You have been selected as a participant because you are a healthy male age 20 to 40 years who is currently actively involved in rock climbing. Should you decide to participate, your response to a health history questionnaire will be reviewed by an exercise physiologist and, if satisfactory, you will be asked to participate in the tests described below.

Purpose of the Study

The purpose of this study is to determine the physiological and physical characteristics associated with different levels of rock climbing ability.

Explanation of Procedures

Muscular Strength Tests (approximately 30 minutes required)

This test will involve measuring the maximal strength for extension of your dominant leg at the knee joint and the maximal flexion of the dominate arm at the elbow joint using a Cybex II+ isokinetic strength machine. The Cybex II+ will not generate any resistance at slower speeds of the arm or leg. At faster speeds of movement the resistance will match the force you produce. For the leg strength test, you will be seated on a bench and you will be secured at the thigh, hips and chest by velcro straps for stabilization. Your leg will be attached to a lever arm of the machine by a velcro strap at the ankle. For the arm strength test, you will be on your back in a reclining position with your upper body stabilized with a velcro strap and your hand will be around a hand grip. Both leg and arm strength tests will begin with three to four warm-up trails, followed by three consecutive maximal extension trials at a moderate speed for determination of leg and arm strength.

Grip strength will be determined on an adjustable hand grip dynamometer. The dynamometer will be adjusted according to your hand size. You will be seated with your elbow flexed to 90° holding the dynamometer. You will be asked to give three maximum efforts with both your right and left hand. You will be given rest periods between trials. You will perform the second hand grip test standing up and with the dynamometer held only with your four fingers. Three maximal trials will be performed but without the use of your thumb.

<u>Anaerobic Capacity Test</u> (approximately 10 minutes required)

The anaerobic test will consist of pedaling simultaneously on a stationary bicycle and an arm ergometer against resistance as fast as possible for 30 seconds. The test will be preceded by a warm-up period and followed by a cool-down period. The bicycle is fitted with toe-clips to reduce the risk of slipping off the pedals. You will begin pedaling against a light resistance and on the command "GO" will begin pedaling as fast as possible. The resistance will be increased to the appropriate level (based on your body weight) within the first 2-3 seconds of the test. Verbal encouragement will be given to motivate you to give a maximal effort.

<u>Body Composition and Size Test</u> (approximately 30 minutes required)

This portion will involve two types of testing: anthropometry and underwater weighing. Anthropometry involves measuring height, circumferences, diameters, and skinfold thicknesses at specific body sites. Underwater weighing involves three measurements: body weight, body weight while under water, and residual lung volume (the amount of air left in your lungs after a complete exhalation). For residual lung volume you will be seated in a chair and will be breathing room air through a mouthpiece. At the end of a normal expiration a valve will be turned so that you will breathe a mixture of helium and air from a spirometer. Oxygen will be added to the spirometer as needed. After breathing from the spirometer for several minutes you will be asked to breathe in fully and then exhale fully. The whole procedure will be repeated, for a total of two trials. To obtain body weight while underwater, you will sit on a 4 inch wide canvas sling which will be suspended from a scale. You will be about neck deep in water. The water temperature will be about 75° to 78°F. You will be asked to tuck up your knees and bend your head forward so that you are completely underwater, while you are underwater you will blow as much air from your lungs as possible.

You must try to remain tucked underwater for about 5 to 10 seconds before coming up, to allow a scale reading to be made. These procedures will be repeated 6 to 10 times with rest intervals between each. These body composition procedures are not stressful and they do not present any risk to your safety.

Leg and Arm Ergometry (cranking) for Cardiorespiratory Endurance (approximately 45 minutes)

Your maximal oxygen consumption and ventilatory threshold will be determined from a test which will involve simultaneous pedaling on a stationary bike and arm cranking at progressively increasing levels of resistance. Your expired air will be collected through a mouthpiece connected to rubber tubing. Your heart rate will be monitored by six electrodes attached to your chest. Following the measurement of a resting heart rate and blood pressure you will begin pedaling and cranking against a light resistance at 60 rpm. Every three minutes the resistance will increase in both the arms and the legs until you can no longer continue at the required pace of 60 rpm. The test will end when you indicate that you no longer wish to continue or your responses (heart function, respiration, and/or physical appearance) indicate that you should not continue or you have reached your maximal effort. It is anticipated that the test will last 15-20 minutes. Following the completion of this test, the resistance will be reduced so that you can recover comfortably. You will continue cooling down until your heart rate is less than or equal to 120 bpm.

Risks and Discomforts

Underwater Weighing:

The water quality in the tank is maintained daily, however there is the possibility of certain types of infections. This is very unlikely due to the daily chemical treatments and filtering of the water. Chlorine irritation, swallowing water, and choking are all possible as in any pool situation. There is some discomfort associated with being submerged underwater and the temperature may feel cold.

Skin Fold

You may develop small bruises from these measurements, although this is very unlikely. The pinching sensation from skinfold measurements may cause some discomfort. You may also feel uncomfortable standing still for these measurements as you will be wearing either just your shorts or swimsuit.

Residual Lung Volume

Some persons experience faintness and/or dizziness when performing this breathing test. The discomfort associated with this test may come from breathing through a mouthpiece with a nose clip in place. Some persons may experience discomfort when performing the maximal inhalation and the maximal exhalation.

Cardiorespiratory Endurance:

Some discomfort and dryness in the mouth, throat, and chest as a result of the restricted breathing, may occur. You may feel lightheaded, fatigued, and slightly nauseous for a short time following this test. Also the discomforts commonly associated with exercise: sweating, increased heart rate, increased breathing rate, and elevated body temperature. Before the test some of the hair on your chest will be shaved off for placement of the EKG electrodes. When you are at or near maximal exercise you may experience abnormal blood pressure, fainting and/or dizziness, muscle fatigue or cramps, and abnormalities in heart beat. If abnormalities are detected in pulmonary function or electrocardiographic recordings, you will be excluded from this investigation.

Stength and Anaerobic Responses:

You may experience some muscle soreness and fatigue following these tests as well as increased heart rate, increased breathing rate, elevated body temperature, sweating , and fatigue during the test. After the maximum anaerobic test you may feel faintness and/or dizziness and possibly slight nausea.

Grip Strength:

You may experience some muscle soreness and fatigue in your hand and forearm. During the test you may feel a increase in heart rate and blood pressure.

Benefits from Participation in the Study

You will benefit from this study by receiving feedback on muscular strength, anaerobic work indices, body composition and size, and cardiorespiratory endurance characteristics. The study will benefit the population in general by identifying those physiological indices that differentiate between performance levels in rock climbers.

Assurance of Confidentiality

The results of this investigation may be used for research publication and presentation. Your right to confidentiality will be protected unless your express consent is granted prior to the publication or presentation of the data.

Withdrawal from the Study

You may withdraw your consent and discontinue your participation in this study at any time (including during the testing) without prejudice. You may also decline to answer any question or item on the health history questionnaire.

Testing will be supervised and conducted by Dr. Craig J. Cisar, Certified Exercise Test Technologist and Wendy Russum, a graduate student. Certified CPR personnel will also be present during testing.

If you have any questions about the investigation now or during the testing, please feel free to ask. If additional questions come-up later or in the case of emergency, call; Wendy Russum (408) 739-3894 or Dr. Craig J. Cisar (408) 287-8132 and either person will be happy to answer them. In the case of any complaints during or after testing , you may contact Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies and Research, at (408) 277-2943.

Consent

By signing this form, you are agreeing that:

(a) you have decided to participate in this study having read the information provided above:

(b) you understand the discomforts and risks involved;

(c) you understand you can withdraw at any time;

(d) you understand that your name will be kept confidential except with your express consent.

SIGNATURE ______________________________ DATE ____________

PRINT NAME ______________________________

SIGNATURE OF WITNESS ______________________________

SIGNATURE OF INVESTIGATOR ______________________________

Appendix B

SAN JOSE STATE UNIVERSITY
DEPARTMENT OF HUMAN PERFORMANCE

PRE-EXERCISE TESTING
HEALTH STATUS QUESTIONNAIRE

____
Date

Name ____________________ Occupation ____________________

Work or Campus Address ____________________ Work or Campus Phone ____________________

Home Address ____________________ Home Phone ____________________

Personal Physician ____________________ Physician's Phone ____________________

Age _____yrs. Height ____ft. ____in. Weight _____lbs. Sex _____

Does the above weight indicate: a gain ____, a loss ____, no change _____ in the past year? How many pounds? ______

A. Joint-Muscle Status (Check areas which you currently have problems)

Joint Areas

( ) Wrists
( ) Elbows
( ) Shoulders
( ) Upper spine and neck
( ) Lower spine
( ) Hips
( ) Knees
( ) Ankles
( ) Feet
( ) Other ____________________
____
____

Muscle Areas

( ) Arms
( ) Shoulders
( ) Chest
( ) Upper back and neck
( ) Abdominal regions
( ) Lower back
( ) Buttocks
( ) Thighs
( ) Lower leg
( ) Feet
( ) Other ____________________
____

B. Health Status (Check if you previously or currently have any any of the following conditions)

( ) High blood pressure
( ) Heart disease or dysfunction
( ) Peripheral circulatory disorder
( ) Lung disease or dysfunction
( ) Arthritis or gout
( ) Edema
( ) Epilepsy
( ) Multiple sclerosis
( ) High blood cholesterol or triglyceride levels
( ) Acute infection
( ) Diabetes or blood sugar level abnormality
( ) Anemia
( ) Hernias
( ) Thyroid dysfunction
( ) Pancreas dysfunction
( ) Liver dysfunction
( ) Kidney dysfunction
( ) Neural dysfunction
( ) Others that you feel we should know about: ____

____
____
____
____

C. Physical Examination History

Approximate date of your last physical examination ______________

Physical problems noted at that time ______________________

When was the last time your resting electrocardiogram was evaluated? ______________________

Was it normal? Yes ( ) No ( ) If no, what was abnormal about it? ______________________

When was the last time you had your electrocardiogram evaluated during an exercise stress test? ______________ What heart rate did you reach during this exercise? __________ Was the electrocardiogram normal? Yes ( ) No ( ) If no, what was abnormal about it? ______________________

Has a physican ever made any recommendations relative to limiting your levels of physical exertion? Yes ( ) No ( ) If yes, what limitations were recommended? ______________________

D. Current Medication Usage (List the drug name and the condition being managed)

Medication	Condition
______________	______________
______________	______________
______________	______________

E. Physical Perceptions - Indicate any unusual sensations or perceptions. (Check if you have recently experienced any of the following during or soon after physical activity (PA); or during sedentary periods (SED).

PA	SED		PA	SED	
( )	( )	Chest pain	( )	( )	Light headedness
( )	( )	Heart palpitations	( )	( )	Loss of balance
( )	( )	Unusually rapid breathing	( )	( )	Loss of coordination
			( )	( )	Extreme weakness
( )	( )	Overheating	( )	( )	Numbness
( )	( )	Muscle cramping	( )	( )	Mental confusion
( )	( )	Muscle pain	( )	( )	Other ____________
( )	( )	Joint pain			________________
( )	( )	Nausea			________________

F. Family History (Check if any of your blood relatives - parents, brothers, sisters, aunts, uncles, and grandparents - have or had any of the following)

( ) Heart disease
( ) Heart attacks or strokes prior to age 50
( ) Elevated blood cholesterol or triglycerides level
( ) High blood pressure
( ) Diabetes

G. Current Habits (Check any of the following if they are charactersitic of your current habits)

( ) Occupation is physically demanding
( ) Occupation is emotionally stressful and/or hectic
( ) In your leisure, you regularly do manual garden or yard work
( ) In your leisure, you regularly go for long walks
( ) You frequently ride a bicycle
( ) You engage in an exercise program more than once per week. If so, what does this consist of? ________________________
( ) You smoke tobacco: ( ) cigarettes ( ) cigars ( ) pipe
_________ number per day (packs, cigars, or pipeful)

CONTINUE TO NEXT PAGE

H. Rock Climbing Experience

Years of rock climbing experience ________________

How often do you climb ________________

How often do you go bouldering ____________

Do you do any training on a regular basis ____________

List the type of training and how often per week.

(ie., running, weight training, cycling)

1)______________________

2)______________________

3)______________________

4)______________________

How would you rate your self according to the following criteria:

Novice	(climb 5.0 - 5.7)	( )
Intermediate	(lead 5.8 - 5.10)	( )
Advanced	(lead 5.11 - 5.13)	( )

What free climbing rating level do you consistantly climb at:____.